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IIHR FLUME STUDY

SCOPE OF WORK (DRAFT)

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STUDIES TO DETERMINE SCALE EFFECTS ON FLOW FIELDS AROUND DIKES AND BENDWAY WEIRS

[Subject area: Open-channel flow and sedimentation (CHL-3)]

INTRODUCTION

Described here is a scope of work for a set of studies whose overall objective is to delineate scale effects on flow fields around hydraulic structures commonly used for alluvial-channel control. Also described is an auxiliary effort to provide guidance on the use of large-scale particle image velocimetry (LSPIV), a useful technique with which to record and diagnose flow fields around hydraulic structures. The guidance will be provided to Mr Andy Gaines of the Army Corps of Engineers. The scope of work is described with the possibility in mind that its studies might be carried out at the Iowa Institute of Hydraulic Research (IIHR).

FLUME STUDIES

The studies entail laboratory flume experiments aimed at establishing scale effects on the flow field around the following two types of hydraulic structures commonly used for controlling channel-thalweg location:

1. dikes (a relatively narrow structure that extends above water surface); and,
2. bendway weirs (a submerged and broad-crested structure).

The information developed from the flume studies will aid interpretation of information obtained from loose-bed hydraulic models (especially small-scale, geometrically distorted models) used to investigate channel-stabilization issues. In particular, the information will aid interpretation of information produced by micro-models. It is intended that the information be combined with information obtained from a companion study (conducted by Mr Andy Gaines of the Corps' Memphis District) focused on scale effects incurred with small-scale and vertically distorted loose-bed models.

Scale Effects

The flume studies will focus on scale effects consequent to varying degrees of similitude relaxation with variations of the following scale considerations:

Horizontal-length scale, X_r

Vertical distortion, G = vertical-length scale/horizontal-length scale, Y_r/X_r

Relative roughness, $(k/R)_r$

In which k = hydraulic-roughness height, R = hydraulic radius, and r = scale ratio.

These three scale considerations are of great practical importance when replicating the flow field around hydraulic structures such as dikes and bendway weirs. They influence key criteria that govern the similitude of the flow fields replicated in hydraulic models. Reynolds-number (inertia/viscous force) similitude and Froude-number (inertia/gravity force) similitude, notably, are directly affected by the three scale considerations. Weber-number (inertia/surface tension) similitude is an additional concerns for very small models.

Lack of Reynolds-number similitude will be evident in differences in flow field around a structure such as a dike or a bendway weir. It is of interest to determine how relaxation of Reynolds-number similitude influences the flow field around a dike or bendway weir; e.g., affecting the strength and frequency of eddies. That information is of use in determining the veracity of results obtained when replicating dike performance in very small-scale models.

Lack of Froude-number similitude will influence flow profiles and patterns around a dike or a bendway weir. Loose-bed models typically do not attain Froude-number similitude, because they primarily focus on attaining mobile bed conditions rather than on explicit simulation of flow resistance. Lack of Froude-number similitude also may affect the flow field around a hydraulic structure, because the approach-flow velocity and its distribution are not scaled in accordance with gravitational forces. For a loose-bed model, proportionately greater velocity magnitudes and gradients usually result around modeled structures, such as bridge piers.

Additionally, lack of relative-roughness similitude will influence velocity gradients, and thereby result in lack of flow-profile and –pattern similitude.

The flume experiments will involve variations of X_r, G, and k/R. By monitoring the flow patterns around a simulated dike and bendway weir, the effects of lax similitude of Reynolds number, Froude number and relative roughness will be evident.

Program of Experiments

Table 1 indicates an overall total of three sets of experiments would be carried out for each structure (dike, bendway weir):

Set 1 - Length-scale effects (c. 5 basic expts per model structure)
Set 2 - Vertical-distortion effects (c. 6 additional expts per model structure)
Set 3 - Relative-roughness effects (c. 6 additional expts per model structure)

It is envisioned that about seventeen individual experiments will be needed to adequately identify the scale effects for each structure. The total number of expts for the two structures would be thirty-four. The experiments are selected so that sufficient observations would be obtained to define clear trends. Additional experiments would be conducted as found necessary during the course of the studies. For example, some (say three) more tests might be run to illuminate scale effects consequent to lack of Froude-number similitude. Such tests would entail varying flow rate for a given combination of horizontal and vertical scales. The horizontal scales indicated in Table 1 are approximate, and intended only to indicate the relative variation of scales from experiment to experiment.

For each hydraulic setting of the flume, the usual procedure would be first to conduct a test with a simulated dike. Once the flow field observations had been recorded, a simulated bendway weir would be placed in the flume, and the test repeated. Subsequently, flume width and flow depth would be adjusted for the next values of the parameter to be tested. For each length-scale, flow conditions would be set in accordance with Froude-number similitude.

Experimental Setup

Briefly described here is a flume setup that would be implemented at the Iowa Institute of Hydraulic Research (IIHR).

Flume. The experiments would be conducted using a flume that has a maximum width of 1.60 m, a length of 20 m, and a maximum depth of 0.6 m. The flume's width would be adjusted, by means of an internal wall, so as to accommodate simulated dikes and bendway weirs of length ranging from 25 mm to 400 mm (a horizontal-scale range of 16). The flume's adjusted widths would be commensurate with a factor of at least six times the lengths of the simulated dike or bendway weir; a factor of six is commonly taken to be adequate to ensure that flow-constriction effects are not significant. Flow depths in the flume would be adjusted as required for the conditions listed in Table 1.

The test section would be located at a 0.6-meter-long sidewall window, thereby facilitating side views of the flow field over the full depth around the simulated dike and bendway weir.

Inlet and Outlet Conditions. These would be controlled by way of a headbox and a tailbox. The headbox would be sufficiently far upstream of the test location so that the simulated dike and bendway weir would be placed within a fully developed turbulent boundary layer flow that is representative of flow conditions in a river.

Bed Roughness. Aluminum sheets coated with fixed roughness elements would be placed along the invert of the flume. The flume's slope would be adjusted (steeper with greater roughness) to produce the same flow depth for a constant flow rate.

Model Dikes and Bendway Weirs. The basic length and width of the simulated dikes and bendway weirs would be proportioned to match those typically used for such structures.

Measurements and Observations

The effects of horizontal scale, vertical distortion, and relative roughness would be interpreted from series of images of the water-surface flow field around the simulated dike and bendway weir. Those images would comprise the main product of the flume studies. They would be recorded using a digital video camera, then quantified for velocities and flow patterns using particle-image velocimetery (LSPIV) and image-processing algorithms. The video camera would be positioned directly above the location of the simulated dike or bendway weir. Small, buoyant polypropylene beads (diameters of 3 mm and 0.5 mm; specific gravity of 0.90) would be used as imaging particles. They would be released upstream of the test section and collected downstream of it.

Additionally video-camera records would be made of the flow patterns throughout the flow depth around the simulated dike and bendway weir. Flow visualization would be facilitated with dye, which would reveal the major features over the depth of the flow field.

Analysis and Reporting

The recorded flow patterns would be converted into vector fields of flow. Changes in the flow fields would be interpreted in terms of Reynolds-number, Froude-number, and relative-roughness similitude. Selected features of the flow field (e.g., size of key vortices, vorticity and periodicity of key eddies) would determined. Degradation of simulation accuracy would be determined in several ways. On way will be by comparing selected flow features measured for the flow conditions studied. Curves would be developed that relate degradation of flow-field accuracy to X_r, G, and $(k/D)_r$. The curves would include an ordinate showing varying Reynolds number, and, for some cases, varying Froude number.

The results of the flume studies would be documented in a comprehensive report submitted to the Corps of Engineers. The report would contain flow patterns determined by means of LSPIV, as well as all quantitative interpretations obtained from them. A videotape record of the flume tests would accompany the written report.

Schedule

The flume studies could be carried out in a six-month period. There is some advantage to allowing a one-year period over which to conduct them; e.g., the studies could be conducted interactively with the study conducted by Mr Gaines. The studies could begin immediately.

Personnel

If the flume studies were conducted at IIHR, Dr Marian Muste could carry out the studies, with oversight and interpretive involvement by Dr Robert Ettema. A graduate research assistant, who would conduct the flume tests as part of a thesis effort for attaining the Masters Degree, could aid them. Drs Muste and Ettema would interact closely with Dr Myanord, Mr Gaines, and Mr Davinroy of the Corps.

Budget

The main budget items would be the time involvement of Dr Muste and a Research Assistant. A modicum of time would be charged by Dr Ettema, as his involvement would could be covered in part through his present contract with the Corps. A modest amount of funds would be needed to cover workshop expenses in setting up the studies. Possibly, some communication and travel costs would be incurred.

GUIDANCE ON LSPIV USE

This part of the scope of work concerns the effort that Dr Muste would spend in guiding Mr Andy Gaines through the procedure for using LSPIV to obtain flow-velocity vectors flow patterns recorded using digital video camera. The procedure entails seeding and video-recording flow patterns, and it entails use of image-processing software.

It is desirable, but possibly not critical, that Mr Gaines use LSPIV in his study of scale effects in small-scale models of alluvial-bed morphology; variations in the bed conditions resulting from the experiments will provide the essential information sought from his experiments. LSPIV, nonetheless, provides a way for conveniently quantifying flow fields; at least, for quantifying surface flow patterns. Mr Gaines could use LSPIV to document the flow conditions associated with selected loose-bed experiments, and use the resulting flow documentation to help in diagnosis of the experimental results.

Several options exist for processing LSPIV images obtained by Mr Gaines:

1. Mr Gaines to acquire commercially available PIV software. Some training would be needed in order to use the software efficiently. Dr Muste could provide the training.
2. The image-processing could be done at IIHR using IIHR's software, under the supervision of Dr Muste. The video images would be recorded by Mr Gaines, then sent to IIHR for processing.
3. A graphical-user interface (GUI) could be developed at IIHR, so that IIHR's software could be used readily by Mr Gaines. Dr Muste could provide the training needed to run the GUI.

These options on ways to proceed can be discussed during a visit to IIHR by Mr Gaines.

Schedule and cost issues could be discussed also during his visit.

DRAFT
05/23/00

Table 1. List of Study cases

Study Series	Structure	Varied Parameter	Length (mm)	Flow Depth (mm)	Approx. X_r	structure Aspect Ratio	G	k/R
I-1	dike	X_r	400	80	10,000	5	1	smooth
			200	40	20,000	5	1	smooth
			100	20	40,000	5	1	smooth
			50	10	80,000	5	1	smooth
			25	5	160,000	5	1	smooth
I-2a	dike	Y_r	200	80	20,000	2.5	2	smooth
			200	160	"	1.25	4	smooth
			200	320	"	0.625	8	smooth
I-2b	dike	Y_r	25 50	20	80,000	2.5	2	smooth
			50	40	"	1.25	4	smooth
			50	80	"	0.625	8	smooth
I-3a	dike	k/R	200	40	20,000	2.5	2	0.01*
			200	40	"	1.25	4	0.05*
			200	40	"	0.625	8	0.1*
I-3b	dike	k/R	25 50	20	80,000	2.5	2	0.01*
			50	20	"	1.25	4	0.1*
			50	20	"	0.625	8	0.2*
Series II	Bendway weir				Same as for dike			

* nominal value

- Distortion Testing

1/3 River Width

Structure

Chann Width

Channel Aspect Ratio

Sinuousity vs slope
Schuum & Kenn

Clarian — 319-351-5049

Hampton Inn → 319-351-6600

I-80-1 Exit into Iowa City

1st Ave & I-80

Dir. to Lab →

Hyd Lab. near River → South Pkg Lot next to River

3rd Floor